An apparatus and method for sonic welding and materials forming

U.S. Patent Application of:

William Harvey Sproat.

"Express mail" mailing label number EL 962409245 US

Date of Deposit: 3 March 2004

I hereby certify that this correspondence, including the attachments listed on the accompanying New Utility Patent Application Transmittal, is being deposited with the United States Postal Service "Express Mail Post Office to Addressee" service under 37 CFR 1.10 on the date indicated above and is addressed to
Mail Stop Patent Applications
Commissioner for Patents
P.O. Box 1450
Alexandria, VA 22313-1450.

William H. Sproat
(Typed or printed name ot person mailing paper or fee)

William H. Sproat
(Signature of person mailing paper or fee)

Title of the Invention

An apparatus and method for sonic welding and materials forming

Cross Reference to Related Applications

U.S. Patent Documents

4,780,867	October 1988	Lind, et al	369/100.
4,899,030	February 1990	Miyazaki	219/121.
5,104, 027	April 1992	Persson	228/107.
6,548,792	April 2003	Durand	219/617.
6,571,593	June 2003	Chung, et al.	72/262

Foreign Patents

US3702674	November 1972	Bodine	B23K1/06

Statement Regarding Federally Sponsored Research or Development

Not Applicable

Description of Attached Appendix

Disclosure of Invention "High Energy Pulse (HEP) Welding", dated 3 September 2003

Background of the Invention

The term sonic, for purposes of this invention, is defined as a wave-like

oscillation of matter induced by either a stress impulse or cyclic stress. The terms wave and impulse are interchangeable within the context of illustration and description of this invention. The term impulse is intended to convey the meaning of a transient sonic event; multiple impulses means repeated transient sonic events. Wave modes described in this invention are the following:

Compression or longitudinal, wherein oscillations are along the direction of travel or propagation, and shear or transverse, wherein oscillations are at a right angle to the direction of travel or propagation.

Mode conversion is the transformation of compression oscillations in one sonic wave propagating medium, impinging at an angle at the interface with a second sonic wave propagating medium, wherein shear oscillations are exhibited in the second medium. In general, the shear mode of propagation is supported by solid materials exhibiting linear elastic shear behavior. In particular, high rates of shear, induced by impulse transients, result in a nonlinear dynamic shear behavior of materials characterized as non-Newtonian viscoelastic. For sake of convenience in this document, the term viscoelastic implies non-Newtonian behavior. The shear mode of propagation terminates in the viscoelastic medium, expending its energy in material change-of-state from linear elastic to viscoelastic.

When a compression mode impulse is superimposed on a volume of viscoelastic material, rapid displacement of the material takes place in response to transient compression stress. This invention applies sonic lens configurations to attain high-power-density; i.e., high-rate of energy transfer within a confined volume of material, by superposing compression and shear impulses.

Waveguide, impulse transit delay line, and sonic impedance transformation characteristics are inherent features of the apparatus disclosed herein. These characteristics are basic underlying principles of sonic wave behavior and are not elaborated in the description and claims exhibited in the disclosure of this invention.

In the disclosure of this invention, fusion is cohesive joining of contiguous materials. Welding is a process of fusion by dispersion of cohesive inhibiting substances. Adhesion is the bonding of contiguous dissimilar materials by molecular attraction. Materials forming is a process of deformation and substructure modification.

Prior Art

This invention relates generally to the field of solid state welding and materials forming, and more specifically to an apparatus and method of sonic welding, materials forming, and materials substructure modification. The impulse nature of this invention is analogous to explosion welding, wherein materials are joined by driving one element of a subassembly into another with controlled detonation of a shaped charge. The collision of objects has a mechanical impulse character which disrupts inherent metal surface oxides, exposing the base metal to cohesively fuse along contiguous surfaces. Another similar prior technology is percussion welding in which workpiece elements are joined by heating with an electrical arc between them, followed by repeated compression impulses to induce fusion. Ultrasonic welding is an additional technology with features similar to the present technology. Here, the elements to be fused are subjected to high frequency oscillations in which contiguous surfaces exhibit a thermal fusion behavior arising from mechanical friction at interfaces.

Materials forming features of this invention are similar to a vibrational energy assist to static and quasistatic forming process that reduces the static load required for deformation. It is also similar to electromagnetic pulse induction forming of metals in which induced current creates reactive forces that bear on the workpiece, driving it to conform to a planned shape.

Metals substructure modification aspects of this invention are processes which are similar to conventional thermoelastic and thermoplastic processes; this invention replaces heat with sonically induced viscoelastic behavior.

Brief Summary of the Invention

The primary object of this invention is to significantly increase both tensile and shear load properties of joints formed with impulse driven fasteners by introducing an adjunct fusion ring around the fastener. Another object of the invention is to devise a materials joining process which requires very short time intervals, thus affording high through-put rates. Another object of the invention is to integrate the apparatus with existing commercial tools, thus minimizing capital investment. A further object of the invention is minimal unit cost addition to achieve high-value-added properties for fastener installations. Yet another object of the invention is the ability to conduct reliable fastening and welding processes with low operator skill requirements.

Yet another object of the invention is to provide a wide range of applicability for materials joining with similar and dissimilar metals, and non-metallics. Another object of this invention is absence of thermal hazards and high intensity light flashes common to conventional welding processes. Another object of the invention is to avert residual

stress and heat affected zones accompanying conventional thermal welding processes.

A further object of the invention is low tooling costs for materials forming by negating the need for high bearing loads. Yet another object of the invention is elimination of filler metal for metals joining.

Other objects and advantages of the present invention will become apparent from the following descriptions, taken in connection with the accompanying drawings, wherein, by way of illustration and example, embodiments of the present invention are disclosed.

In accordance with a preferred embodiment of the invention, there is disclosed an apparatus and method for *sonic welding* of materials comprising:

superposition of a sonic shear wave impulse and a sonic compression wave impulse converging simultaneously within a workpiece. Said sonic shear wave impulse transforms materials from a solid state to a viscoelastic state. A sonic compression wave impulse, also introduced by said sonic lens, impinges on said materials transformed to a viscoelastic state to induce material displacement.

Said sonic lens, or lenses may be positioned in single or multiple configurations adapted to varying requirements. Said apparatus functions with a range of energy sources, including but not limited to: single or multiple explosive charges, single or multiple mechanical impacts, single or multiple pneumatic impulses, and single or multiple electrodynamically driven impulses.

Said sonic shear wave energy is derived and partitioned from said sonic compression wave impulse through a refraction angle, codependent with inherent sonic wave velocities of said sonic lens and said workpiece. Said sonic lens spatial

distribution and configurations provide for coincident transit times of said sonic compression wave impulse and said sonic shear wave impulse into said workpiece. Said sonic lens composition and shape are covariable. Said energy source, or sources, may be modulated to optimize sonic power spectral densities in said workpiece. Materials in said apparatus are selected for inherent sonic velocity and impedance attributes to attain required impulse transmission, reflection, refraction, and mode conversion properties. Sonic waveguides may be applied for impedance matching among said energy sources, said sonic lens, and said workpiece.

In accordance with a preferred embodiment of the invention, there is disclosed an apparatus and method for *sonic deformation, bonding and substructure modification* of materials comprising: superposition of a sonic shear wave and a sonic compression wave impulse impinging simultaneously within a workpiece. Said sonic shear wave impulse is introduced into said workpiece through a sonic lens, or lenses, which introduce a high-power-density within the body of, or at interfaces among, contiguous elements of said workpiece. Said sonic shear wave impulse transforms materials from a solid state to a viscoelastic state. Said sonic shear wave impulse is induced by a sonic lens which creates a high-shear-power density within the body of said workpiece. Said sonic compression wave impulse applies positive stress on said materials transformed to said viscoelastic state. Said sonic compression wave impulse is induced by said sonic lens which creates a high-compression-power density within the body of said workpiece. Said sonic lens is positioned in one or multiple configurations adapted to application requirements. Said apparatus functions with a range of energy sources,

including but not limited to: single or multiple explosive charges, single or multiple mechanical impacts, single or multiple pneumatic impulses, and single or multiple electrodynamically driven impulses. Said sonic shear wave energy is derived and partitioned from said sonic compression wave impulse, directed by refraction angles codependent with inherent sonic wave velocities of said sonic lens and said workpiece . Said sonic lens spatial distributions and configurations provide for superposition of said sonic compression wave impulse and said sonic shear wave impulse through adjustment of impulse transit time for each said sonic impulse origin. Said sonic lens composition and shape are covariable. Said energy sources may be modulated to generate a desired range of power-spectral-densities. Materials in said apparatus are selected for inherent sonic velocity and impedance attributes to attain required impulse transmission, reflection, refraction, and mode conversion properties. Sonic waveguides may be applied for impedance matching among said energy sources, said sonic lens, and said workpiece.

Brief Description of the Drawings

The drawings constitute a part of this specification and include exemplary embodiments to the invention, which may be embodied in various forms. It is to be understood that in some instances various aspects of the invention may be shown exaggerated or enlarged to facilitate an understanding of the invention.

Figure 1 is an overall cross sectional view of the invention according to the first embodiment. All components are cylindrical sections about a centerline axis.

The referenced numeral 21 identifies a ring shaped zone of fusion between two elements of of the workpiece, identified as numeral 22 and numeral 24. The referenced numeral 29 identifies a sonic lens affixed to the incident element of the workpiece identified as numeral 22. The referenced numeral 23 identifies a sonic lens contiguous to the opposing surface of the workpiece. The referenced numeral 25 identifies a cartridge containing an explosive charge. Expanding gases from ignition of the explosive charge, confined by the hollow cylinder numeral 26, drive the piston impactor numeral 27 to: firstly, drive a penetrating pin numeral 28, and then simultaneously impact the sonic lens numeral 29 and incident surface of the workpiece.

An impact generated sonic compression impulse is induced in both the workpiece and the sonic lens numeral 29. The sonic compression impulse, incident on the tapered peripheral extremes of sonic lens 29, is refracted into the workpiece as a shear impulse. The compression impulse transmitted through the workpiece is reflected back by the sonic lens 23. This reflected compression impulse is geometrically partitioned into normal incidence and angled incidence on the plane of contact with the workpiece. The angled incidence is such that the compression impulse within lens 23 is refracted into the workpiece as a shear mode.The reflected compression impulse, having normal incidence to the workpiece, remains in the compression mode. A high-power-density superposition of shear and compression impulses induces viscoelastic behavior and material displacement in the workpiece, especially around the pin where the two elements of the workpiece, numerals 22 and 24 are pin restrained. The resultant workpiece fusion zone coincides with the spatial distribution of superimposed shear and compression mode impulses. Fusion is effected in multilayer

workpieces, in addition to the above described two layer case. Figure 2 is an expanded view of the sonic lenses 29 and 30 and the workpiece 22 and 24. It illustrates the sonic compression and shear mode profiles. The pin is excluded from this depiction for sake of clarity. Downward pointing arrows, illustrated within the body of the piston impactor 27, represent the incident compression impulse. The illustration view on the right half of figure 2 exhibits two shear mode profiles, both identified by the letter S, as refracted from compression impulses propagating within the bounds of sonic lenses 29 and 30, into the workpiece. The illustration view on the left half of figure 2 shows three reflected compression mode profiles, all identified by the letter C, as propagating within the bounds of lens 23. These compression mode profiles have been geometrically partitioned into both normal and angled incidence on the workpiece by angled facets on the lower extreme of sonic lens 23. The high-power-density arising from superposition of shear and compression mode impulses induces viscoelastic behavior and material displacement in the workpiece. Zones of fusion arise where superimposed shear and compression impulses displace metal oxide surfaces. Parent metal cohesion takes place in a volume of material depicted by the cross-hatched boundaries identified by numeral 21. All components of the apparatus and depictions of shear mode and compression mode profiles described above are shapes of revolution about a centerline axis. For sake of clarity in figure 2, shear mode profiles are shown on the right half of the illustration and compression mode profiles are shown on the left half of the illustration.

Figure 3 depicts views of the second embodiment of this invention, intended to form and cohesively fuse materials, activate adhesive agents among workpiece

elements, and modify intrinsic materials substructure. Figure 3-I is a detailed cross sectional view of a rod shaped sonic lens acting as a forming element numeral 35, along with a matching die numeral 32; which represents the second embodiment of this invention. The view in figure 3-I depicts a downward quasistatic load with dashed arrows identified with the letter Q, and an impact on the forming element by downward pointing arrows, along with the internal composition of the sonic lens attributes of the forming element. The lens consists of two different materials, identified by numerals 33 and 34, which act to geometrically partition the impact generated compression impulse into both normal incidence and angled incidence along interfaces common to the workpiece.

Figure 3-II illustrates, with arrows, two compression impulse directions within the lens. The numeral 36 shows the direction of a compression impulse aimed into the workpiece at normal incidence. The lens compression impulse numeral 37 is refracted at the internal bi-material lens interface, and thence directed at the lens-to-workpiece interface at an angle that induces refracted shear mode propagation within the workpiece. The high-power-density superposition of shear and compression impulses induces viscoelastic materials behavior. Material displacement is driven by both the external quasistatic downward load, depicted by numeral Q in figure 3-I, and the compression impulse. The workpiece yields to a relatively low stress in zones where shear and compression modes are superimposed.

The view in figure 3-III depicts the next forming stage with direction of one compression impulse numeral 39 directed from bi-material lens refraction. Normal incidence of this sonic compression impulse on the workpiece transmits into the

workpiece as compression impulse. Sonic compression impulse numeral 38 is directed at angled incidence on the workpiece to induce a refracted sonic shear impulse within the workpiece. The superposition of shear and compression impulses is in a zone different from that in figure 3-II. The workpiece undergoes deformation with continued quasistatic downward load within a second zone of superimposed shear and compression impulses. This two-staged process allows for a more controlled and complex shaping capability than one using a conventional forming processes. Description of this embodiment uses only two forming stages for sake of clarity. Multiple stages are desirable for more complex forms.

The apparatus and processes described in figures 1 through 3 can be applied to modify material substructure, promote cohesion, and activate bonding agents for adhesion among workpiece elements, including metallics and nonmetallics.

The sonic lenses depicted in figures 1, 2, and 3 are specific examples of numerous possible configurations designed to induce shear mode impulses, coincident with compression mode impulses, in single or multi-element workpieces. Shear modes are derived from angular incidence of a compression impulses on the interface between: two contiguous dissimilar materials, the sonic lens, and the workpiece with each material exhibiting different inherent velocity of sonic wave propagation. Additionally, the sonic lenses are designed to impart phase or amplitude coherence of the shear and compression modes within the zone, or zones of wave mode superposition by selectively establishing impulse transit times from source-to-workpiece, through length of wavepath and inherent shear and compression wave velocities of materials.

Detailed Description of the Preferred Embodiments

Detailed descriptions of the preferred embodiment are provided herein. It is to be understood, however, that the present invention may be embodied in various forms. Therefore, specific details disclosed herein are not to be interpreted as limiting, but rather as a basis for the claims and as a representative basis for teaching one skilled in the art to employ the present invention in virtually any appropriately detailed system, structure or manner.

The invention in its first embodiment relates to solid state welding. Solid state welding is a group of welding processes which produce coalescence at temperatures essentially below the melting point of the base materials being joined, without the addition of brazing or filler materials. The oldest of these processes, forge welding, belongs to this group. Other processes include cold welding, diffusion bonding, explosion welding, friction welding, hot pressure welding, and ultrasonic welding. The exhibited apparatus and processing methodology differs from prior art in that:

Energetic impulse sources may be selected from a number of forms such as: explosive charges or cartridges, mechanical impactors, single and multiple impact pneumatic sources, and electromagnetically impelled impactors. A sonic lens (or lenses) transforms compression wave impulses by refraction, accompanied by mode conversion and energy partition, into directed shear impulses, Said refraction is attained by selection of sonic lens material with sonic wave velocity having defined ratio to the sonic wave velocity in the workpiece. The shape and composition of said sonic lens are therefore, covariable.

Said sonic lens directs and superposes compression impulses to coincide with the shear impulses, to impinge on selected zones in the workpiece. This phenomenon is a spatial and temporal event where shear and compression impulses are simultaneous in time and space, characterized as phase or amplitude coherence. The sonic impulse transit time from the source to the selected zones in the workpiece is adjusted with lens shape and composition, and waveguides or delay lines a appropriate. Sonic filters and impedance matching elements may be inserted along sonic wave paths to optimize power-spectral-densities and energy transfer. Sonic lenses may be positioned in arrays to attain desired sonic energy transfer configurations.

Specifically, the first embodiment of this invention improves on prior welding technology by:

A. Superposing shear and compression impulses of sufficient energy density and rate, in watts/square millimeter, to simultaneously drive metals in a workpiece from solid to viscoelastc state, and to dynamically forge contiguous elements within the workpiece by displacing cohesive inhibiting substances;

B. Combining plastic state and forging compression in metals, including dissimilar metals, to produce fusion, and fusing nonmetallic materials by activation of elements or agents at interfaces, or within the body of workpieces, or dispersion of adhesive inhibiting substances by exposure to superposed shear and compression impulses.

Primary advantages afforded by this invention, in contrast to prior art are:

C. Economy in energy consumption by concentrating energy at fusion interfaces;

D. Greater control in directing energy to fusion sites by sonic lens placement;

E. Flexibility in processing a wide range of workpiece shapes, mass and composition with options available in sonic lens designs and arrays;

F. Absence of deleterious metallic welding process residual effects, such as heat affected zones, alloy segregation, and residual stress;

G. Inherent ability to make ultrasonic nondestructive inspection an integral part of the process by monitoring ultrasonic spectral elements of the incident, transmitted and reflected impulses;

H. Safety factors accompanying the primary advantages are avoidance of thermal and optical flash hazards accompanying most conventional welding processes; and

I. Expenditure of consumables such as filler material is negated;

The invention in its second embodiment relates to forging, cold forming, and thermomechanical processing of metals. The oldest of these processes is blacksmithing, where metals are heated to induce plastic behavior and driven with repeated mechanical impulses to shape and form workpieces. The exhibited technique differs from the above prior art in that sonic shear impulse energy replaces thermal energy and sonic compression impulse energy replaces forging energy.

The present invention relates to metals thermomechanical processing by imparting sonic shear impulses to replace heat and imparting sonic compression impulses to replace conventional mechanical deformation. On a substructure scale, the sonic shear and sonic compression impulses drive dislocations in a highly controlled manner to transform metal properties. Primary advantages realized by the subject invention over prior art are:

J. More efficient use of energy through focusing and directing sonic shear and sonic